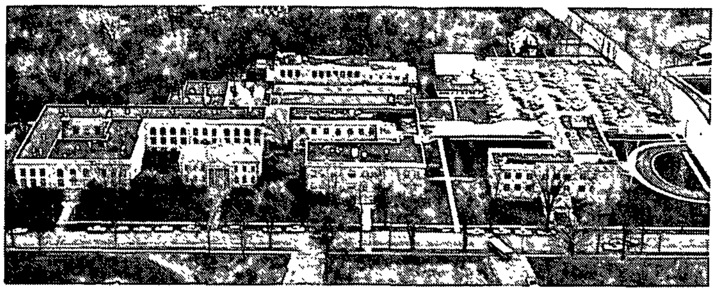

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PAPERMAKING FACTORS AFFECTING BOX PROPERTIES

W. J. WHITSITT

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Papermaking Factors Affecting Box Properties

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PAPERMAKING FACTORS AFFECTING BOX PROPERTIES

W. J. Whitsitt
Container Group Leader
The Institute of Paper Chemistry
P.O. Box 1039
Appleton, WI 54912

ABSTRACT

This study was directed to determining the effects of selected papermaking changes in the manufacture of linerboard and medium on combined board and box compression properties. The effects of the following factors were considered: increased wet pressing, reduced directionality, and strength additives. Our results show that linerboards made with increased wet pressing exhibit higher compressive strengths due to increased fiber bonding. Combined boards made with more highly wet pressed liners exhibit increased ECT and flexural stiffness. This indicates that the increases in liner compressive strength are more important to box compression properties than the reductions in thickness accompanying wet pressing. Reducing the MD/CD stiffness ratio of the liners increases ECT and has little effect on the geometric mean flexural stiffness of the combined board. Based on the McKee box formula, higher box compressive strength should be achieved with more highly wet pressed liners and liners with lower MD/CD ratios.

INTRODUCTION

During their service life, corrugated containers are often subjected to high compressive loads. Therefore, compressive strength is the single most important end-use requirement for corrugated boxes. McKee, et al. (1) showed that the top load compressive strength of a box is dependent on two properties of the combined board. They are edgewise compressive strength (ECT) and flexural stiffness. Their work reveals that ECT is about three times more important than flexural stiffness.

ECT is mainly dependent on the compressive properties of the components; combined board flexural stiffness depends primarily on the elastic moduli of the liners and to a limited extent on the medium. Both are also dependent on corrugating quality.

Recently, we have shown that the compressive strength of paperboard is related to the elastic moduli of the board because the fibrous elements within the board become unstable and buckle (2). (Note: the terms elastic moduli or stiffness refer to the Young's moduli of the paperboard.) These moduli can be conveniently measured using nondestructive ultrasonic techniques (3). Our work has shown that the elastic moduli are well related to the compressive strength of containerboard and to ECT (4). Because of their nondestructive nature, ultrasonic techniques can be used in the laboratory and on the paper machine to monitor and control product quality (5).

Various relationships between the combined board properties and containerboard properties have been developed. For example, ECT is commonly predicted from the compressive strengths of the components. However, there has been concern that such relations would not hold when containerboard is wet pressed more and becomes thinner. These concerns have intensified as our industry has begun to improve compressive strength via improved pressing and lower MD/CD ratios. Some of these same concerns arise when efforts are made to select liner and medium components to optimize box compression strength for a given combined board weight (6,7).

To show how selected papermaking changes affect ECT and combined board flexural stiffness, linerboards were made having different ratios of CD compressive strength to the bending stiffness. (Note: to avoid confusion between the bending properties of the components and combined board, the term "bending stiffness" will refer to the component property; "flexural stiffness" will refer to the combined board property.) Special mediums were also made to determine the effects of increased wet pressing on runnability and combined board strength. The tests on the combined boards made from these materials were analyzed to show the effects of the following papermaking factors: increased wet pressing, reduced MD/CD ratio and selected strength additives.

As part of our current work, various relationships between combined board and component properties are being examined to determine their accuracy when papermaking and other conditions are varied. Another goal of our work is to incorporate the elastic moduli of the components in such relationships. This will allow use of the expanding technology of ultrasonic testing to characterize board and box performance. The results of these analyses will be summarized in a future paper.

LITERATURE REVIEW

The relationship between ECT and component characteristics has been analyzed in two main ways. The first and simplest approach is to sum the compressive strengths of the components allowing for the draw of the medium. This approach gives good predictive accuracies if based on appropriate statistical weighting factors.

In the second approach, combined board is treated as a structure comprised of narrow flat plate elements of liner between flute tops and flat or curved plates of medium (Fig. 1). These miniature plate elements could become unstable and buckle in the same way that a box panel buckles in top load compression. When such local buckling occurs, the combined board ECT could be dependent on the edgewise compression and bending properties of the liners and medium. Various papermaking factors can affect the compressive and bending properties of containerboard in different ways, e.g., wet pressing or refining. It has been speculated that if local buckling is of importance, then factors such as improved wet pressing of the liners and medium might not increase ECT and box compression in the expected way because of the decreases in component thickness.

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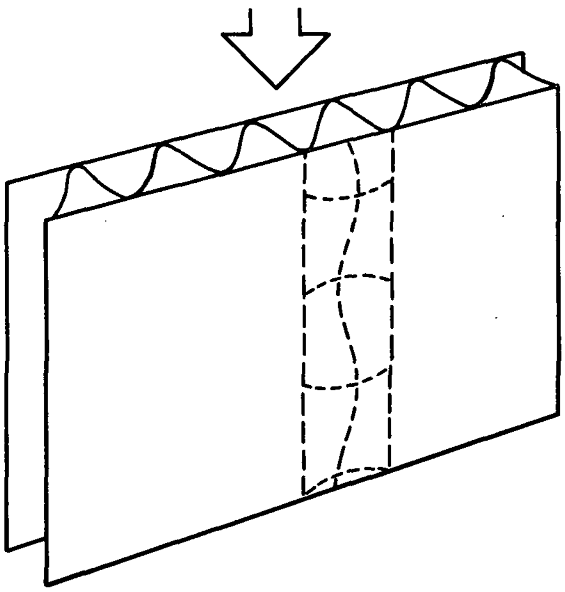

Fig. 1. Corrugated board showing component plate elements.

The second approach has been pursued by workers at the Institute, the Forest Products Laboratory, and other locations (8-10). The more recent model by Johnson treats the combined board component elements as a case of inelastic buckling and assumes the components are isotropic rather than orthotropic. The solutions are nonlinear and require empirically fitted CD compressive stress-strain curves. This approach requires specialized testing (11) and a sophisticated computer analysis. As one alternative, ECT may be analyzed using the same approach as used in developing the McKee box formula (10). In this approach the compressive failure of each miniature plate element will depend on the edgewise compressive strength and bending stiffness of the liner or medium element; then the ECT strength equals the sum of the liner and medium miniature plate element compressive strengths. In past work good agreement with observed ECT strengths was obtained (10) using this approach.

The combined board flexural stiffness in each direction is estimated by summing the products of the elastic modulus of each component times its moment of inertia relative to the neutral axis of the combined board (12-14). As a good approximation combined board stiffness is equal to $EtH^2/2$ for a balanced constructed where E is the elastic modulus of the liners, t is liner thickness, and H is the combined board caliper. Thus, papermaking factors which increase E in the appropriate direction and t will increase the combined board stiffness in that direction. Combined board flexural stiffness is sensitive to the caliper of the combined board; thus, it is necessary to avoid crushing the board during conversion.

EXPERIMENTAL PROCEDURES

To determine how selected papermaking factors affect board and box properties, experimental linerboards and mediums were made. The linerboards were fabricated into combined board on the Institute's pilot corrugator using a 26-lb commercial medium. The experimental mediums were combined with commercial 42-lb liners.

The experimental linerboards and mediums were made using a Formette Dynamique sheet former and dried on a belted drum press to simulate machine pressing and drying. Two sets of sheets were prepared for this study under varying conditions as follows:

Set 1. Experimental Linerboards. The sheet making conditions were varied to give linerboards with varying ratios of compressive strength to flexural stiffness in order to check the effects of liner bending stiffness on combined board and box properties. For this purpose 33-, 42-, and 69-lb liners were made at three wet pressing levels with a MD/CD elastic modulus ratio of about 2.5. At the intermediate wet pressing level, liners were made having MD/CD elastic modulus ratios of about 3, 2.5, and 1.0. Some additional sheets were made with a starch additive using application rates of 2 and 4%. The furnish was a 100% softwood kraft pulp.

Set 2. Experimental Mediums. The 26-lb oriented mediums were made using three wet pressing levels. A furnish comprised of 75% semichemical fiber and 25% softwood kraft was used. The linerboards and mediums were tested for compressive strength following the TAPPI procedures for ring crush and STFI short span compression. The in-plane and thickness direction elastic moduli were determined using the procedures developed by Baum and co-workers (5). The combined board tests were carried out using TAPPI procedures.

DISCUSSION OF RESULTS

Papermaking Effects - Linerboard

As wet pressing is increased, fiber-to-fiber bonding and sheet density increase; hence, most sheet properties increase. For example, the CD short span compression results for linerboard in Fig. 2 increase as density increases. Thus, from a compression standpoint the denser liners would be expected to increase ECT and hence, box compressive strength.

In contrast the geometric mean bending stiffnesses of the liners decrease with increasing density as shown in Fig. 3. This would be expected because the bending stiffness of the liners is dependent on the cube of the thickness and Young's modulus. The increases in density due to increased wet pressing decrease thickness sufficiently to counterbalance the increases in elastic moduli obtained by densification. Figure 3 shows that large changes in the bending stiffnesses of the liners were obtained in this study. If the bending stiffnesses of the liners have an important effect on combined board ECT, then large decreases in the bending stiffnesses of the liners due to increased densification would be expected to lower ECT and hence, box compressive strength. One of the objects of the present work is to test this hypothesis.

As the MD/CD ratio of the sheet is decreased (Fig. 4), the CD STFI short span compressive

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strengths of linerboard increase. Thus, making a squarer linerboard sheet would be expected to increase ECT and box compressive strength. On the other hand changing the MD/CD ratio has little effect on the geometric mean bending stiffness of the liners (Fig. 5). Therefore, the bending stiffness changes for the linerboard will not affect the geometric mean flexural stiffness of the combined board and hence, box compression (from the McKee formula). These changes in the MD/CD ratios of the liners provided another way to determine if the bending stiffnesses of the liners have a major effect on box compressive strength.

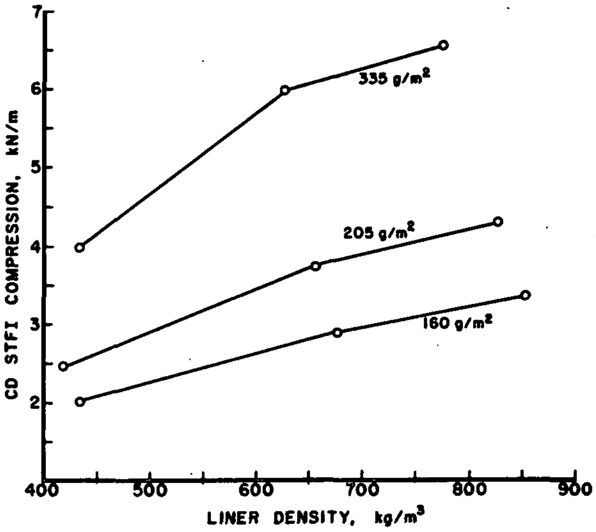

Fig. 2. CD STFI short span compressive strength increases as wet pressing and hence, density increases.

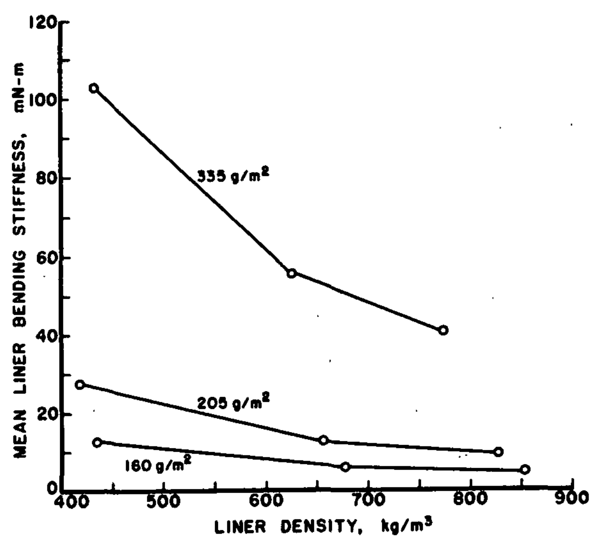

Fig. 3. Geometric mean bending stiffnesses of linerboard decrease as density increases.

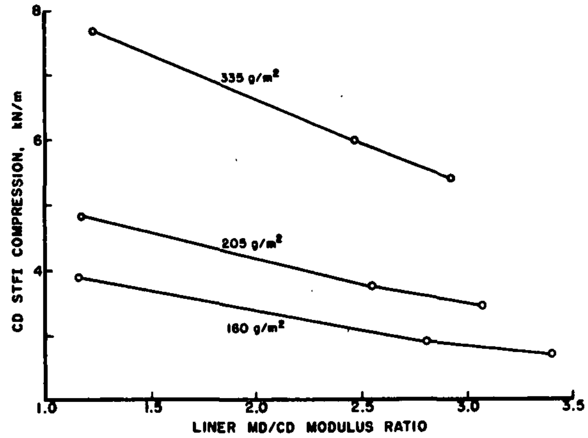

Fig. 4. CD STFI short span compressive strengths of linerboard increase as the MD/CD stiffness ratios are decreased.

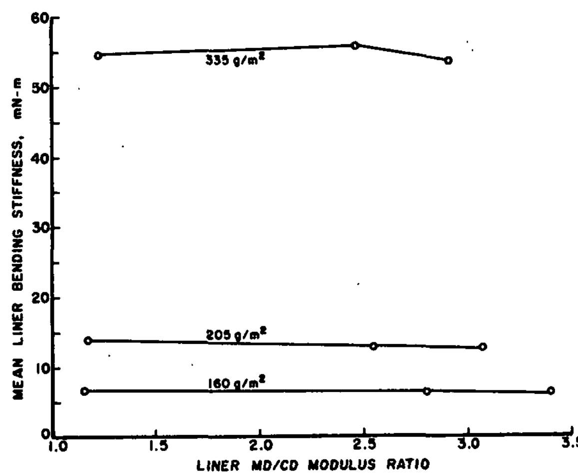

Fig. 5. Geometric mean bending stiffnesses of the linerboards are not greatly affected by MD/CD ratios.

Some of the experimental linerboard sheets were made with a starch additive to increase fiber-to-fiber bonding. Two levels of addition, 2 and 4% were used. The starch treatments tended to increase compressive strength and the bending stiffnesses of the liners. However, the effects of the treatments were smaller than obtained with the wet pressing and MD/CD ratio changes discussed previously.

Figure 6 compares the short span compression and bending stiffness results on the 205 g/m^2 liners for the papermaking changes discussed above. The changes in MD/CD ratio increased the STFI strength by about 50% but made only a small change in the bending stiffness of the liners. Increased wet pressing decreased the flexural stiffness by a factor of three but increased STFI compressive strength by 40%. The results for the 160 and 335 g sheets show similar trends (not illustrated).

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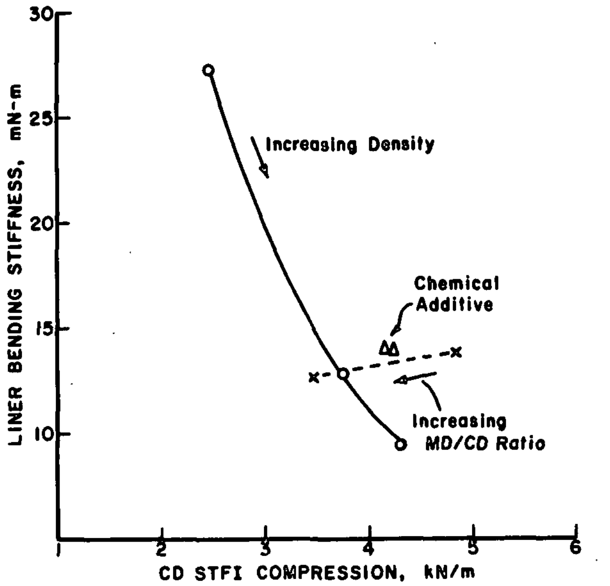

Fig. 6. Effects of papermaking factors on the short span compression and bending stiffness of 205 g/m^2 linerboard.

As mentioned previously the CD compressive strength of paperboard is related to the elastic moduli in the CD and thickness directions, E_x and E_z, respectively. Figure 7 shows that CD STFI short span compressive strengths are highly related to the elastic stiffness function derived by Habeger and Whitsitt (2). The predicted relationship holds for all of the papermaking conditions used in making these linerboard sheets. In general the elastic moduli of paperboard are affected by wet pressing (Fig. 8) and MD/CD ratio in the same way as compressive strength. Thus, these results show that the ultrasonic moduli can be used to predict compressive strength.

Papermaking Effects - Combined Board

The linerboards made under the conditions described above were combined with a 26-lb commercial medium on the Institute's pilot corrugator. The single-faced board was then double-backed and the combined board was tested for ECT and flexural stiffness.

Increasing the density of linerboard by wet pressing increased combined board ECT (Fig. 9). This held true for combinations made with 33-, 42-, and 69-lb liners. Thus, densification of the liners is an effective way to increase the compressive strength of the combined board and should contribute to increased top load box compressive strength.

Figure 10 shows that combined board flexural stiffness is increased by using the stronger liners obtained by increased wet pressing. The increases in combined board flexural stiffness were achieved at all three liner basis weight levels. Even though wet pressing decreased the thickness of the liners, the combined board flexural stiffness increases because the increase in elastic moduli of the liners more than counterbalances the decreases in liner thickness.

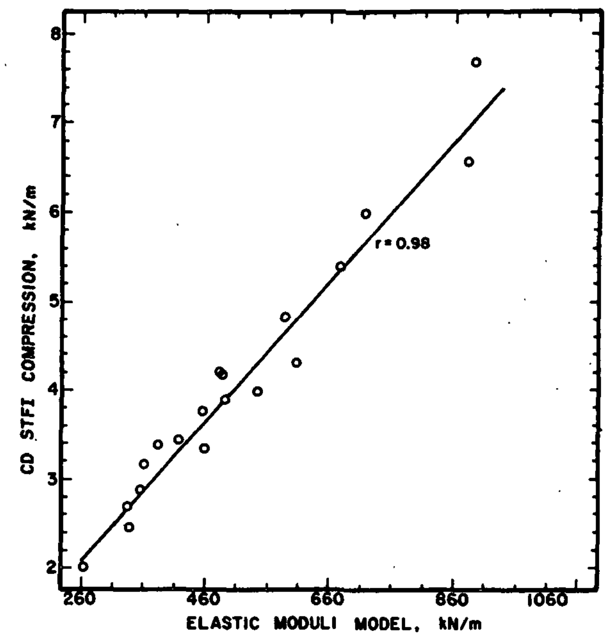

Fig. 7. CD STFI compression results are highly related to the product of the elastic moduli in the CD and thickness directions as predicted by theory.

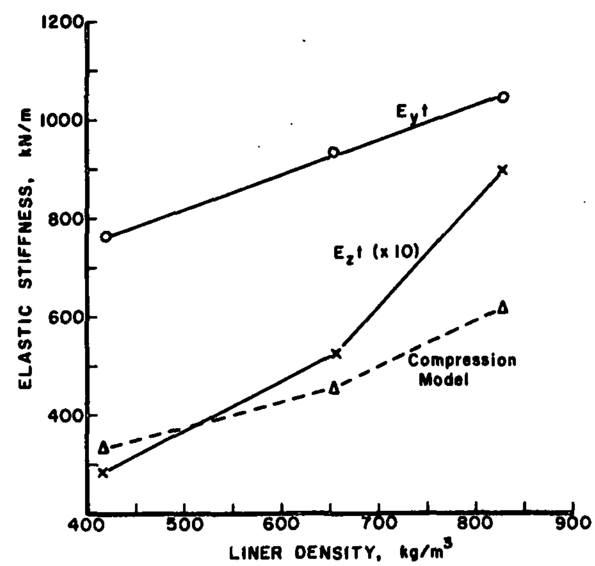

Fig. 8. The elastic moduli used to predict CD compressive strength increase with density in the same way as compressive strength.

Thus, using the thinner but stronger and stiffer liners increased both material properties in the McKee box formula, namely ECT and flexural stiffness.

Therefore, box compressive strength should increase as liner density is increased by improvement in wet pressing during manufacture.

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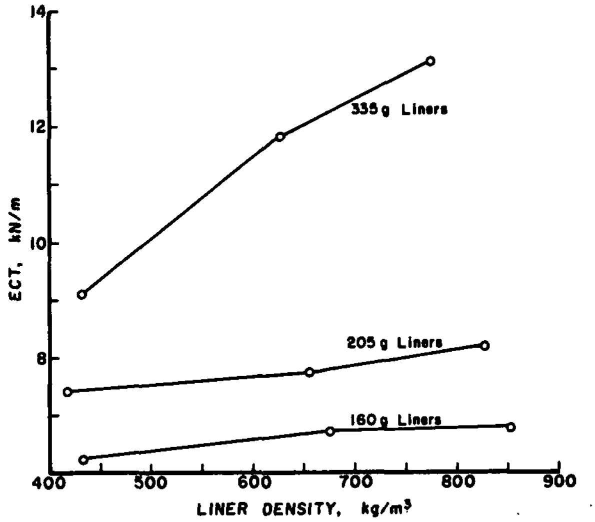

Fig. 9. Increasing liner density via wet pressing increases combined board ECT.

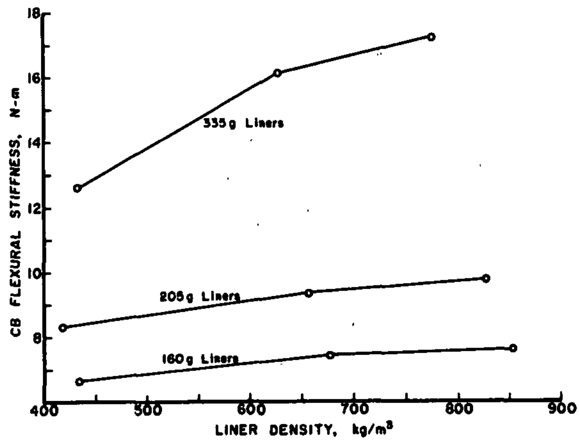

Fig. 10. Increasing liner density vis wet pressing increases combined board flexural stiffness.

Despite the fact that densification reduces the bending stiffness of the liners, ECT increases. Thus, it appears that ECT strength is primarily dependent on the compressive strength of the components; the thickness and bending characteristics of the liners have only a limited effect at a given basis weight. Local buckling models which place too much emphasis on the latter factors could underestimate the potential improvements in ECT performance from papermaking factors such as wet pressing.

Making a squarer linerboard increases ECT strength as shown in Fig. 11. This would be expected because CD compressive strength increases as fewer fiber elements are aligned in the machine direction, drying restraints held constant. On the other hand the geometric mean combined board flexural stiffness is not affected by changing the MD/CD ratio of the liners (Fig. 12). In this case the increases in CD flexural stiffness are counterbalanced by the decreases in MD stiffness.

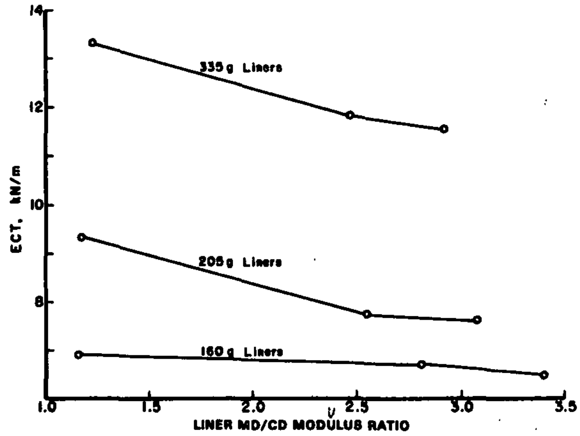

Fig. 11. Decreasing the MD/CD modulus ratio of linerboard increases combined board ECT.

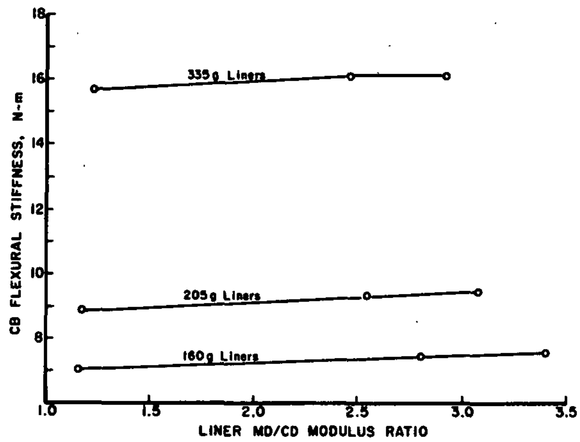

Fig. 12. The geometric mean combined board flexural stiffness is not affected by changes in the MD/CD modulus ratio of linerboard.

Therefore, box compressive strength should be increased by papermaking changes which reduce liner MD/CD ratios because of the increases in ECT. Work is in progress to validate these box predictions and compare the various ECT models which have been proposed.

Papermaking Effects - Medium

In past work we have made and tested mediums which were wet pressed to increase their density, compressive strength and hence, their strength retention during fluting (15). Densification improved most strength properties including the STFI short span compressive strength. However, CD ring crush passed through a maximum at a density of 750-800 kg/m^3 (Fig. 13). Compression tests on the combined board showed that increasing the corrugating medium density markedly increased ECT strength (Fig. 14). Thus, the STFI short span compressive strength test results on the medium were more indicative of combined board performance.

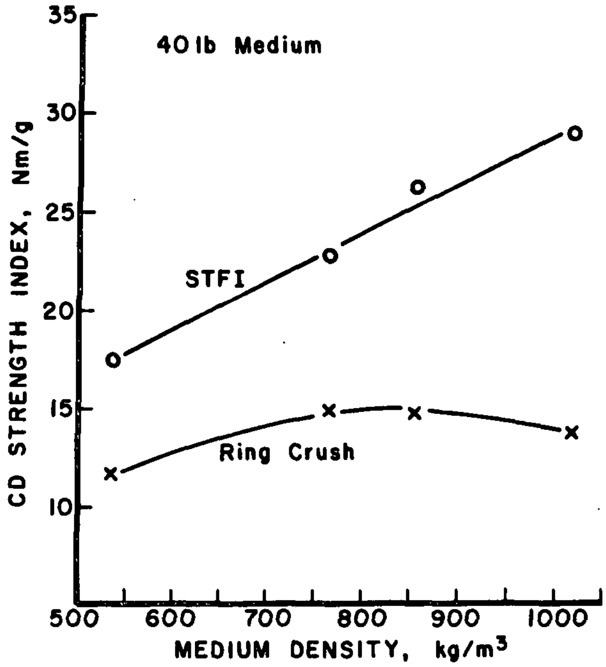

Fig. 13. Increasing medium density increases CS short span compressive strength, but ring crush results exhibit a maximum at intermediate densities.

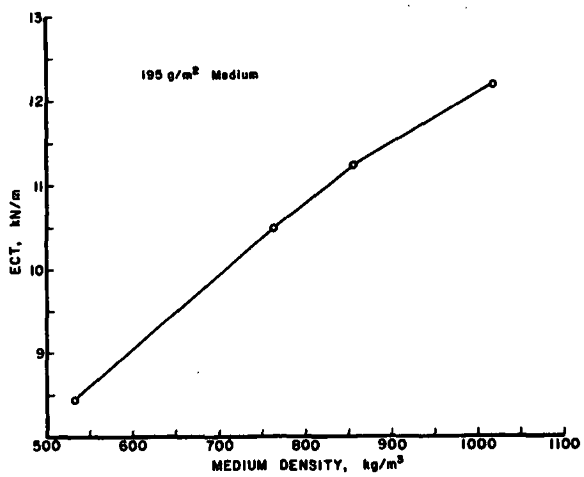

Fig. 14. Increasing medium density increases ECT.

The increases in ECT strength due to the use of denser, stronger medium result in higher box compression results. In addition the stronger medium increases flat crush strength and hence, reduces crushing during conversion and end-use.

CONCLUSIONS

In this work we have determined the effects of making papermaking changes in the manufacture of linerboard on combined board and box properties. The results show:

1. Increased wet pressing improves the compressive strength of linerboard but reduces its bending stiffness.

2. Combined boards made with linerboards which are more highly pressed exhibit improved ECT. This indicates that ECT is primarily dependent on the compressive strength of the liners; the thickness and bending stiffness characteristics of the liners apparently have a much smaller effect.

3. Combined boards made with densified liners by wet pressing exhibit higher flexural stiffnesses despite the fact that wet pressing reduced liner thickness.

4. Reducing the MD/CD ratio of linerboard increases the CD compressive strength of the liners and hence, ECT, but has little or no effect on the geometric mean flexural stiffness of the combined board.

5. Based on the McKee box formula higher box compressive strength should be achieved with more highly pressed liners or liners with lower MD/CD ratios.

ACKNOWLEDGMENTS

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